The Fairchild Papers

Endgame in the Pacific

Complexity, Strategy, and the B-29

G. Scott Gorman
Major, USAF

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Foreword

Endgame in the Pacific: Complexity, Strategy, and the B-29, by Maj G. Scott Gorman, inaugurates an Air University Press series of substantive essays considered too short for publication as monographs but too lengthy to be journal articles.

The series is named for Gen Muir S. Fairchild, first commander of Air University and widely regarded as its conceptual father. Although he held no college degree, General Fairchild was a respected leader who was part visionary, part keen taskmaster, and "Air Force to the core." By the time the first classes were meeting at Maxwell Air Force Base, he had succeeded in defining the role of the professional Air Force officer and in blending that role into the curriculum of the first Air University schools.

General Fairchild's legacy is one of optimistic confidence about the future of the Air Force and the central role Air University would play in its development. This series is only one component of that legacy and its prophetic quality.

Endgame in the Pacific examines the challenges encountered by XX and XXI Bomber Commands in employing the B-29 against Japan, first from India and China, later from the Marianas. In turn, it examines the adaptations required to meet those challenges. Air University Press is pleased to present Major Gorman's essay as the first of the Fairchild Papers.

ROBERT B. LANE
Director
Air University Press

About the Author

G. Scott Gorman

Maj G. Scott Gorman, born on 19 November 1963, is a native of Wadsworth, Ohio. Following graduation from the United States Air Force Academy in 1986, he earned the Master of Arts degree in Russian history from Indiana University. Major Gorman is a senior pilot with instructor time in the T-3, the T-37, and the C-5. He has also taught Russian history, world history, and military history at the United States Air Force Academy. Major Gorman is a graduate of US Air Force Squadron Officer School (outstanding graduate), US Army Command and General Staff College (1998), and US Army School of Advanced Military Studies (1999), where this paper was originally developed. He was recently selected as a candidate for a senior service school. Major Gorman is currently stationed at the American Embassy in Moscow, Russia, where he is chief of the US Security Assistance Office. He is married to the former Sarah E. Cummings and is the proud father of three children.

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Abstract

In war, competing systems introduce new technological means to gain advantage. Greater technological complexity, however, creates greater uncertainty—due not only to technical problems but also to unintended consequences when new technology is applied within the chaotic environment of war. In the last years of the war against Japan in the Pacific, Boeing's B-29 was the technological solution to attacking Japan across long distances. Application, however, was not as simple as planners had hoped. Uncertainties and unintended consequences accompanied the B-29's employment.

Introduction

War is an outward expression of competition between complex but adaptive political and military systems. These systems are complex not only because they contain a great number of parts but also because the parts are intricately related to the system and to the external environment. War, as a result of this inherent complexity, is uncertain and chaotic. This uncertainty arises from the characteristic of nonlinearity in war. Like the proverbial flapping of a butterfly's wings that results in a thunderstorm, small changes to initial conditions in war can have disproportionate effects. The living and adaptive nature of opponents is another source of uncertainty in war. War, in sum, is not clockwork; it is an organic interaction between competing complex and adaptive systems.

Strategy is a plan of action for negotiating complexity and uncertainty to achieve a specific goal. Strategy provides unifying direction—a common purpose for actions within the system. Strategy maps out the employment of means to achieve desired objectives. Unlike mathematical or mechanical solutions, military strategy is aimed at a moving target—an intelligent and adapting opponent. Strategy, given the uncertain and changing nature of war, must similarly be flexible and adaptive to achieve desired end-states.

Theater military strategy employs various tools and methods to achieve those desired ends. Technology, which fashions the implements of war through the scientific method, is one tool available to the military strategist. In war, competing systems introduce new technology in an attempt to gain comparative advantage over other systems and the environment. Just as with other inputs within a system, the impacts of technological change are difficult to predict, often resulting in nonlinear effects and unintended consequences. Thanks to the profoundly interactive nature of war, technological tools that were intended to simplify and solve complex problems may in fact foster additional complexity.

In its competition with the Japanese system in the Pacific theater in 1944, the American military system faced the complex strategic problem of ending the war unconditionally while minimizing American casualties. The Boeing B-29 Superfortress was the US Army Air Force's technological solution to this complex strategic problem. The B-29's pressurized cockpit, longer range, more accurate bombing systems, and mechanically controlled defensive systems represented a vast improvement over earlier strategic bombardment technology. Rather than simplifying the problem, however, the B-29 with its uncertainties and unintended consequences (and the intricacies of the relationships surrounding the new technology) further "complexified" it. Employment of the B-29 spawned technological difficulties, awareness of doctrinal failings, personal and interservice rivalries, and Japanese responses—and these consequences created the need for further systems adaptation. The B-29 was not the quick and easy solution promulgated by the Army Air Forces. Only after numerous adaptations at the strategic, operational, and tactical levels—and the marriage of the B-29 with another technological tool, the atom bomb—did the United States achieve its desired strategic end-state.

Future military strategy and the application of technological tools within that strategy should be organic and adaptive, not mechanistic. Strategy should consider both the adaptive nature of the enemy system and the uncertainty of strategic inputs in the chaotic environment of war. Future American military strategists pondering the effects of emerging technology would do well to recall the experience of the B-29 in the Pacific theater during World War II.

This paper first discusses the theoretical aspects of technology in warfare viewed through the lens of complexity theory. It then details the complexity of the strategic problem facing the United States in the war against Japan. Focusing on the role of airpower, the paper presents the strategic bombardment of Japan using B-29s based on the Mariana Islands as a case study in the application of technology to achieve strategic ends. It examines both unforeseen difficulties and the adaptations that were necessary to "make it work." The conclusion offers advice—and caution—for future strategists looking to simplify the complexities of war with linear and mechanical solutions.

Chapter 1

Complexity and Technology in War

Everything in war is very simple, but the simplest thing is difficult.

—Carl von Clausewitz

Uncertainty is an unavoidable aspect of warfare. War, due to its complex and nonlinear nature, is an inherently unpredictable venture. German military theorist Carl von Clausewitz aptly noted the inherent uncertainty of war.[1] For Clausewitz, war was a "true chameleon," ever changing due to the elements of chance, friction, and the dynamic relationship between politics and military operations.[2] Only in Clausewitz's "absolute war," a theoretical war devoid of context and in essence absent the nonlinear relationships of the real world, could the outcome of war be predicted with any certainty.[3] Real war is not so simple. Dynamic interactions within the complex process of war do not lend themselves to this unrealistic theoretical abstraction. "[An] attribute of military action is that it must expect positive reactions, and the process of interaction that results [from the action taken]. . . . The very nature of interaction is bound to make [war] unpredictable."[4]

Greater technological complexity creates greater uncertainty. Innovations in military technology produce quicker, deadlier, and more destructive ways of interacting within the military environment. As a military tool, technology cannot be mechanistically applied within military strategy. The certainty of a machine in an insulated experimental environment does not guarantee certainty in the chaotic environment of war.[5] Although a technological instrument may theoretically represent a closed system intended to perform like clockwork, the environment of war in which it is utilized is an open system subject to imponderable unforeseen inputs having nonlinear effects. This "Machiavellian" desire to rationalize warfare is in part a reflection of the faulty mechanistic view inherited from Newton and passed down through modern military theorists.[6]

Airpower planners, given the technical nature of aircraft and munitions, are particularly susceptible to mechanistic approaches to warfare. Entranced by the technical nature of their tools, airpower strategists tend to view airpower planning as an engineering science, a mere mechanical analysis of weapons and targets.[7] Despite the technical nature of the air instrument, uncertainty is just as important in applying airpower as in applying other military instruments. Gen Haywood S. Hansell Jr. noted the role of uncertainty in the conception of Air War Plans Division-1 (AWPD-1): "In any measurement system involving probabilities, one never reaches certainty. The more bombs you drop, the greater becomes the likelihood of getting a hit, but you never reach absolute certainty."[8] Misled by scientific paradigms and their doctrinal heritage, airmen frequently overlook the inevitable uncertainties entailed in the complexities of war.[9]

Increased uncertainty demands technological and operational adaptation to achieve desired military objectives. Systems adaptation is the constant revising and rearranging of the building blocks of a system to provide advantage over its environment.[10] Adaptation may involve either a change in the technology itself or a change in the way the technology is applied. Adaptation is more than just passive defense and survival of the system; it is a proactive measure to meet change head-on.

Adaptation requires both learning and anticipation. Learning is the gaining of knowledge from the past; anticipation is presumed knowledge of the future. To adapt effectively, a system must recognize both past failures and present opportunities. It must then forecast future conditions to anticipate the adaptations that will be most effective within this new environment. Successful system adaptation requires knowledge of the past and present combined with cognitive anticipation of the future. Military adaptation requires learning about the operational environment, anticipating future changes in that environment, and acting to effect the necessary adaptation.

What is important to note is that human interaction is required. Although machines of the future may change themselves to account for environmental conditions, machines of the past and present do not. Human innovation and ingenuity are the wellsprings of adaptation. Success in war requires not only the mechanical application of technological "rules" but also the creative ability to come up with alternative solutions in the face of uncertainty and environmental change. Innovation is the key to success. In war, and especially in the application of technology to war, thinking is required.

Military systems improve their chances of success by increasing their ability to adapt in a dynamically complex environment. Those that adapt in the face of dynamic complexity survive and prosper; those that fail to adapt do not thrive, often suffering the catastrophic consequences of systemic breakdown. Military failure is essentially the failure to cope with complexity.[11] Eliot Cohen and John Gooch, in *Military Misfortunes: The Anatomy of Failure in War*, stress that military failures are not individual failures, but systemic failures. Misfortune in war is not usually the failure of individuals to act; rather, it is the failure of the system to adequately function within its environment.[12]

Anticipation is particularly difficult because actions within war are aimed at a similarly thinking and adapting enemy. Like other living systems, the military system must contend with an opposing system that is also adaptive and is, in the creative dance of coevolution, seeking to gain an advantage over its opponent.[13] Successful adaptation requires not only efficacy but also speed. A military system has to functionally adapt to its dynamic surroundings, and do it quicker than its adversary. Military operations are not aimed at static, unchanging adversaries; they are aimed at dynamic, thinking, similarly adapting systems that have hostile intentions.[14] Competition motivates adaptation as systems seek to gain advantage over other systems in their environment in what pre-World War II planners identified as the "inevitable interplay of challenge and response."[15]

This systemic coevolution is clearly evident in the application of technology to warfare. The introduction of new technology often instigates a counterresponse from the enemy that negates the intended effects of the new technology. The technical devices of war will be opposed whenever possible by other devices specifically designed against them. Often, the very success of new technology spawns those factors that result in its eventual downfall. In a cycle of "action – reaction," enemy forces focus efforts on countermeasures to neutralize whatever devices are most threatening to their existence. Thus, to be continually successful, technology must continually adapt to changing circumstances.[16] Failures of technology in war are frequently due to failures in adapting to dynamic and complex environments.

Military strategists must recognize the complex and dynamic nature of war. Having identified the desired end-states, military strategists should then allow for uncertainty and adaptation in applying the means to achieve these desired ends. End-states are inextricably linked to the means used to pursue them; one cannot be isolated from the other. Clausewitz affirmed the coevolutionary relationship between ends and means:

> But in war, as in life generally, all parts of the whole are interconnected and thus the effects produced, however small their cause, must influence all subsequent military operations and modify their final outcome to some degree, however slight. In the same way, every means must influence even the ultimate purpose.[17]

In prescribing the employment of technological means, strategists should recognize not only the complex and uncertain nature of warfare; they should also consider the potential impacts of those means upon planned outcomes.[18] Strategists should plan for adaptation to meet the inevitable uncertainties of war.

Having laid a theoretical foundation, we will now present the experience of the B-29 in the Pacific against Japan. The B-29 story will serve as a case study in the application of new military technology. It details the complexity of the strategic problem facing the United States in the war against Japan from late 1944 until the summer of 1945, and it examines the role of the B-29 in solving this problem. In analyzing the B-29 story, this essay asks the following questions:

Did uncertainties and unanticipated consequences accompany the introduction of this emerging technology?

Did these uncertainties further "complexify" the strategic problem?

What manner of adaptations (technological, operational, strategic) were required by the introduction of this increased complexity?

To achieve desired ends, adaptive action must outpace the complex of problems generated by the introduction of new military means. In the war against Japan, US adaptations outpaced the added complexities generated by the introduction of the B-29 in the Pacific.

(US Air Force photo)

A Hurricane-Hunting Superfortress. This B-29, serving as a "Hurricane Hunter," is taking off on the first leg of a 14-hour mission.

Notes

1. Alan Beyerchen, "Clausewitz, Nonlinearity, and the Unpredictability of War," *International Security* 17, No. 3 (Winter 1992/93): 59–90. Beyerchen writes that Carl von Clausewitz understood that "seeking exact analytical solutions does not fit the nonlinear reality of the problems posed by war, and hence our ability to predict the course and outcome of any given conflict is severely limited."

2. Carl von Clausewitz, *On War*, Michael Howard and Peter Paret, eds. (Princeton: Princeton University Press), 1984, 158. Clausewitz clearly identified the nonlinear nature of war and the complex nature of interactions in war. "But in war, as in life generally, all parts of the whole are interconnected and thus the effects produced, however small their cause, must influence all subsequent military operations and modify their final outcome to some degree, however slight. In the same way, every means must influence even the ultimate purpose."

3. Beyerchen, 172.

4. Clausewitz, 139.

5. Ibid., 167. "In war . . . all action is aimed at probable rather than at certain success."

6. John F. Schmitt, "Command and (Out of) Control: The Military Implications of Complexity Theory," *Marine Corps Gazette* (September 1998), 55–56. Since the enlightenment of the eighteenth century, Western theory has centered on scientific interpretations of the world. Specifically, Newtonian physics has shaped Western understanding of cause and effect. Taken from the world of physical mechanics and applied across the academic and social disciplines from psychology to government, Newtonian models speak mechanistically of "the clockwork universe," describing efficient social systems as "well-oiled machines." Military theory is not exempt. Thanks in large part to the nineteenth century fathers of modern military thought, Carl von Clausewitz and Antoine de Jomini, modern military theory also rests upon physical concepts borrowed from the Newtonian paradigm: friction, centers of gravity, geometric points and lines, and mechanical synchronization of military operations. The Newtonian paradigm dominates modern military theory.

7. Barry D. Watts, *The Foundation of U.S. Air Doctrine: The Problem of Friction in War* (Maxwell Air Force Base [AFB], Ala.: Air University Press, 1984), 22–23.

8. Haywood S. Hansell Jr., *The Air Plan That Defeated Hitler* (Atlanta, Ga.: Longino & Porter, Inc., 1972), 10.

9. Watts, 43–58. Watts points out the tendency of American airmen to ignore "the complex amalgam that Clausewitz called 'friction in war'."

10. Mitchell M. Waldrop, *Complexity: The Emerging Science at the Edge of Order and Chaos* (New York: Simon and Schuster, 1992), 146.

11. Watts, 47. "The *sine qua non* of a successful military organization is the capacity to adapt to changing conditions better than the enemy, the implication being that sound theory can do much to facilitate such adaptation."

12. Eliot A. Cohen and John Gooch, *Military Misfortunes: The Anatomy of Failure in War* (New York: Free Press, 1990), 94. Cohen and Gooch identify three reasons for military failure: failure to learn, failure to anticipate, and failure to adapt. Of these three elements, they identify adaptation as the most important capability for a military organization. "Indeed, the ability to adapt is probably most useful to any military organization and most

characteristic of successful ones, for with it, it is possible to overcome both learning and predictive failures."

13. Sun Tzu, *The Art of War*, trans. Ralph D. Sawyer (Boulder: Westview Press, 1994), 193. The ancient Chinese military theorist Sun Tzu recognized the significance of coevolution in military systems when he wrote of the importance of shaping oneself in accordance with the enemy. "Water configures its flow in accord with the terrain; the army controls its victory in accord with the enemy. One who is able to change and transform in accord with the enemy and wrest victory is termed spiritual."

14. Clausewitz, 77, 149. "War is always the collision of two living forces." In declaring war as neither science nor art, Clausewitz writes, "The essential difference is that war is not an exercise of the will directed at inanimate matter, as is the case with the mechanical arts, or at matter which is animate but passive and yielding, as is the case with the human mind and emotions in the fine arts. In war, the will is directed at an animate object that reacts."

15. Hansell, 49. "A highly resourceful enemy such as the Germans found it possible to design effective countermoves. Key areas, for example, could be skillfully defended, dummy factories could be built, camouflage and smoke screens used, air to air defenses strengthened, repair methods improved and refined, and very vital points hardened by putting them underground. During the planning phase, we sensed this inevitable interplay of challenge and response and, as later events proved, we somewhat overestimated our challenge and underestimated their response."

16. Edward N. Luttwak, *Strategy: The Logic of War and Peace* (Cambridge, Mass.: Harvard University Press, 1987), 27–28.

17. Clausewitz, 158.

18. Ibid., 92. "The original political objectives can greatly alter during the course of the war and may finally change entirely since they are influenced by events and their probable consequences."

Chapter 2

Endgame against Japan: The Strategic Problem

AWPD-1, the first plan for the use of American airpower in World War II, was drawn up in 1941 at the behest of President Franklin D. Roosevelt and Gen George C. Marshall. Focused primarily on the air campaign against Germany, AWPD-1 provided little detail concerning any future offensive air war against Japan.[1] The United States would contemplate a strategic offensive against Japan only after victory in Europe was assured. Until then, the burden of defending the western hemisphere against Japanese aggression fell almost entirely on the US Navy. Gen Haywood S. Hansell noted that, prior to the attack on Pearl Harbor, "The American people simply could not believe that Japan would challenge the United States in open warfare."[2] With the attack on Pearl Harbor, the Japanese invalidated Army and Navy prewar planning assumptions in one swift blow.

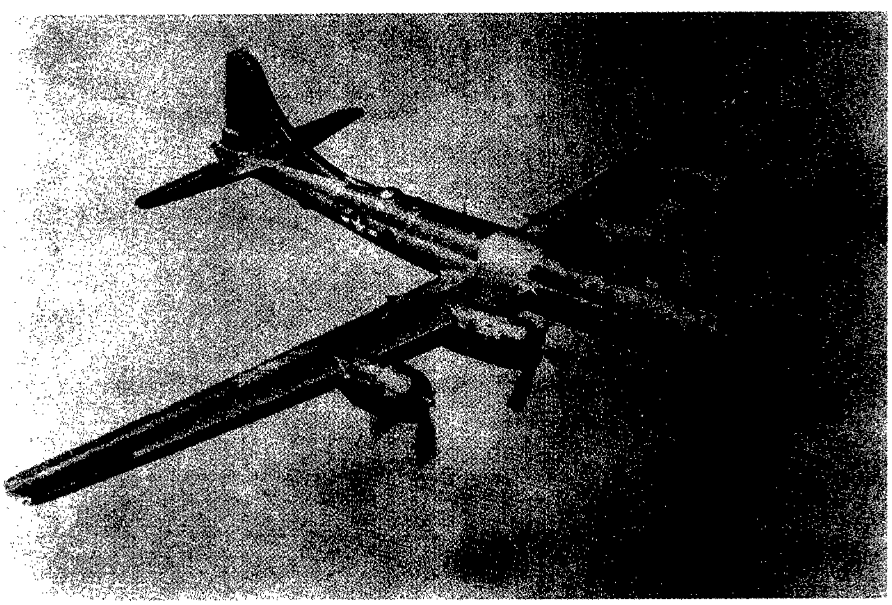
As an island nation, wartime Japan depended upon maintaining her newly won "Co-Prosperity Sphere" in the Pacific region for economic support. Hoping to knock out the American threat to her interests in the Pacific by a preemptive strike in 1941, Japan soon found herself fighting a total war to ensure her survival rather than a limited war to maintain economic resources. By 1943, Japan was on the defensive throughout the Pacific theater; only in China did Japan tenuously maintain an upper hand over her adversary. The "characteristically American" war aim of unconditional surrender declared at Casablanca in January 1943 left little room for military or diplomatic maneuver. Only by forceful occupation of the home island or defeat of Japanese decision makers' will could the war be ended. Adding to the strategic dilemma, US war planners felt that Americans were not patient enough to withstand a long war against Japan. Therefore, despite the "Europe first" *global* strategy, *theater* strategy in the Pacific required continuous pressure against the Japanese to maintain the initiative and win an early surrender.[3]

Theater geography added to the difficulties facing the strategic planners. The territories occupied by Japan fanned across an enormous geographical area, with landmass accounting for only a small percentage of that area. Ocean dominated the 64 million square miles between Hawaii, Australia, the Philippines, and Japan. Unconditional defeat of the Japanese would require crossing that ocean, either by hopping across the chain of islands in the southwest Pacific toward the Philippines and China or by directly crossing the vast expanse of central Pacific ocean toward Japan proper. Initial defense of the Pacific, and the eventual counteroffensive, required the coordinated effort of all three instruments of military power: Navy, Army, and Army Air Corps (renamed Army Air Forces on 19 January 1942). Victory in the Pacific would necessarily be a joint effort. Despite organizational parochialism, which advocated plans focused upon a single service, each instrument faced limitations in the Pacific that could only be overcome by cooperating with the other services.

The US Army in the Pacific under Douglas MacArthur preferred the island route originating from the southwest Pacific. The US Navy under Chester Nimitz saw the Pacific war as a blue-water naval war that demanded direct action across the broad expanse of the central Pacific. In a somewhat ironic twist, the Army Air Force, which coveted bases within striking distance of Japan, supported the Navy's plan for a more direct approach toward Japan.[4] The actual plan, arrived at in the summer of 1943 by the Combined Chiefs, was a somewhat diluted compromise between the services. It embraced a "twin axis" strategy that would allow the Army and the Navy to pursue their own separate plans in contributing to the overall defeat of Japan. The power of personalities and the persistence of service rivalries led the United States to spend tremendous resources in fighting this two-pronged strategy in the Pacific.[5]

Strategic airpower proponents saw differences of opinion between the Army and the Navy as an opportunity to prove the validity of their argument for autonomy of the air arm. The distances involved suggested that the air component might hold a unique advantage over both the Army and the Navy in prosecuting the war. Yet, given the limitations of aircraft range and endurance, even zealots for independence of the air forces were forced to admit the necessity of cooperating with the other services to provide and protect bases for aircraft operating against Japan. Unlike air operations in Europe, where Allied bombers were already within striking distance of Germany, strategic bombing in the Pacific would not be tenable until Allied forces advanced to occupy territory within range of mainland Japan.

In the minds of Army Air Force planners, the Army and the Navy would conquer the geography required to enable independent air operations—and the emerging technology of the Boeing B-29 Superfortress would provide the range and coercion to bring an unconditional end to the war against Japan. As early as October 1940, Gen Henry "Hap" Arnold foresaw the B-29 as the one weapon that could "exert pressure against Japan without long and costly preliminary operations."[6]



(US Air Force photo)

A High-Flying Superfortress. Flying above the clouds, this B-29's mission and destination remain unknown.

Notes

1. Haywood S. Hansell Jr., *The Air Plan That Defeated Hitler* (Atlanta, Ga.: Longino & Porter, 1972), 42–46; Barry D. Watts, *The Foundations of U.S. Air Doctrine: The Problem of Friction in War* (Maxwell AFB, Ala.: Air University Press, 1984), 17–22. The strategic priority of the plan was the war against Germany. The Army Air Force would support a strategic defense in the Pacific and only after the defeat of Germany would there be emphasis on an offensive strategic air war in the Pacific. Watts critiques the mechanistic nature of AWPD-1.
2. Hansell, 34.
3. Russell F. Weigley, *The American Way of War: A History of United States Military Strategy and Policy* (New York: MacMillan, 1973), 281.
4. Ronald H. Spector, *Eagle Against the Sun: The American War with Japan* (New York: Free Press, 1985), 279.
5. J. C. Wylie Jr., "Reflections on the War in the Pacific," United States Naval Institute *Proceedings* 78, no. 4 (April 1952): 357–61.
6. Richard P. Hallion, "Prelude to Armageddon," *Air Power History* 42, no. 3 (Fall 1995): 42.

Chapter 3

Doctrinal and Technological Development

Prewar United States Army Air Corps doctrine stressed the ability of the air arm to independently provide decisive force through strategic air bombardment. Doctrine for strategic bombardment derived and professed by the Air Corps Tactical School (ACTS) at Maxwell Field in Alabama was built around four assumptions.[1] The first of these assumptions, initially espoused by Italian air theorist Giulio Douhet, was that the bomber would always get through. Given the speed, range, and altitude limitations of pursuit aircraft, this assumption was well founded in the 1920s and early 1930s; however, theorists failed to anticipate improved aircraft design and the adaptive development of defensive measures, including radar, that would make the bomber extremely vulnerable without fighter escort.[2] Early British and German experience had demonstrated the vulnerability of the bomber, but Americans ascribed those results not to bombing doctrine but to a lack of sufficient defensive armament on the bombers. Well-armed American "fortresses" and "superfortresses" could do better, they thought.[3] In their second assumption, American planners concluded that high-altitude bombardment held the best chance for success in keeping the bombers clear of ground-based air defense systems and low-altitude fighters. The third American doctrinal assumption was that bombers could accurately deliver precision attacks against individually selected targets. Air planners pointed to the existence of "critical nodes" in enemy infrastructure that could be precisely targeted and destroyed, the result of which would be the collapse of enemy systems. The will of the enemy population was not a suitable direct target but would be secondarily affected by destruction of the nation's infrastructure. Finally, American air planners determined that strategic bombardment during daylight hours would be the most effective tactic in achieving the required precision. Since enemy fighters were assumed to pose no threat, daylight offered the best chance to find and precisely strike discrete targets. From these four basic assumptions, the Air Corps Tactical School developed the doctrine of high-altitude daylight precision bombardment that would guide the strategic use of American airpower until 1945. The independent nature of strategic bombardment doctrine would fuel the Army Air Corps' informal drive for autonomy throughout the war.[4]

To effect the doctrine of daylight high-altitude precision bombardment, American airmen needed bombers that could "fit the bill." In the 1920s and early 1930s, however, technological limitations had impeded bomber development. Only with the improved features of closed cockpits, retractable landing gear, and fully cowled engines, along with developments in metallurgy that allowed the construction of a light, all-metal monoplane, did the possibilities of long-range bombardment become reality.[5]

Using the rubric of coastal defense to justify their position, bomber advocates from ACTS pushed for the development of long-range bombers at the expense of pursuit aircraft.[6] The Army Air Corps fielded the Martin B-10 in the summer of 1932. A significant improvement over previous bombers, the B-10 featured an enclosed cockpit, a monoplane design, larger wings, a power nose turret, and a remarkable speed of 207 miles per hour.[7]

The real leap in bomber development, however, came with the introduction of the Boeing B-17 in 1935, dubbed by its manufacturer "an aerial battle cruiser, a veritable flying fortress." With its unique silhouette, four big engines, impressive defensive armaments, a range of over 2,000 miles, and an average speed of 233 miles per hour, the B-17 Flying Fortress became perhaps the most famous airplane in the history of the Air Corps.[8] But even the improved performance characteristics of the B-17 (and other bombers, like the Consolidated B-24 Liberator) were inadequate for the operational demands of the Pacific theater. What was needed was a *very* long-range (VLR) bomber—one that could exceed 3,000 miles in range with a significantly larger payload than either the B-17 or the B-24. By the end of 1941, the need for VLR bombers had become especially important. The Soviet Union was nearing collapse, Britain's demise was not out of the realm of possibility, and a broad expanse of ocean stood between US operating bases and the Japanese mainland.[9]

Meanwhile, in January 1940, the Army Air Corps had issued a design requirement to American aircraft manufacturers for a VLR bomber.[10] Boeing responded with the B-29 Superfortress; Convair's entry, the B-32 Dominator, was cut short almost at birth by technical difficulties and production delays.[11]

The B-29 was on the cutting edge of aircraft technology when first flown in 1942.[12] Twice as heavy as the B-17, the B-29 could carry a crew of 11 men and a 20,000-pound bomb load a distance of more than 3,000 miles—and it was 30 percent faster than the B-17.[13] But the advanced features of the B-29, progenitor of both American and Soviet modern bomber technology, taxed the limits of American aircraft industry. It was, in fact, so advanced that Boeing designers themselves, fearing they were going too far into the technological unknown, were uncomfortable with the aircraft.[14] The Air Force's program director, Gen Kenneth B. Wolfe, called the bomber a "three-billion-dollar gamble."[15] Nevertheless, given the demands of the strategic environment of World War II, American planners and designers were willing to take the gamble.

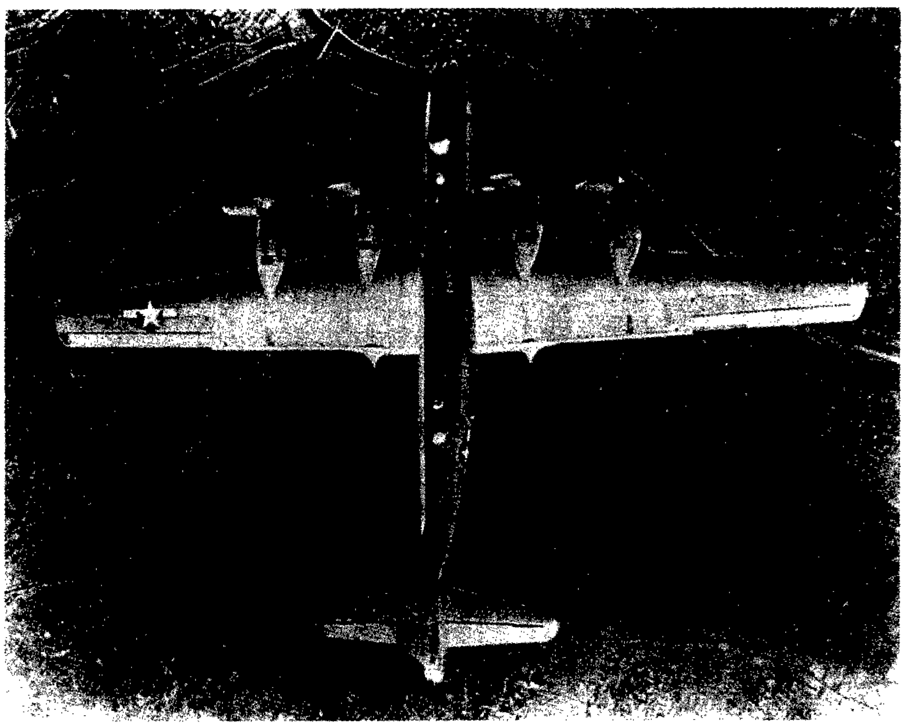
The most technologically advanced aspects of the Boeing B-29 were its engines that provided the necessary range and carrying power, the pressurization system that allowed it to operate at high altitudes, the bombing systems that facilitated precision bombardment, and the automated defensive system that justified the name Superfortress. The 18-cylinder Wright R-3350 engine, the largest engine available at the time, used two superturbochargers to drive propellers 16.5 feet in diameter at 2,200 horsepower.[16] In the 1,200-mile flight from Saipan to Tokyo, the giant engines would consume 6,000 gallons of gas.[17] The engines facilitated the climb to the operational altitude of 30,000 feet and, combined with the huge Boeing "117" wing, gave the B-29 a maximum range of nearly 6,000 miles.

One of the technological demands of high-altitude bombing was the need for aircraft pressurization. Pressurization in the B-29 provided a cabin altitude of 8,000 feet for the crew while flying at an altitude of 30,000 feet. The B-29 had two pressurized sections fore and aft connected by a 40-foot tunnel large enough for men to climb through. This tunnel was a solution to the problem of maintaining pressurization while opening the bomb bay doors. Although not the first combat aircraft to incorporate pressurization (German and British air forces had experimented with pressurized cockpits in combat aircraft), the B-29 was more sophisticated and could pressurize larger crew areas than any of the others.[18]

American strategic bombardment doctrine also required precision delivery of munitions. To meet this requirement, Boeing equipped the B-29 with the Norden bombsight and the AN/APQ-13 radar. Although primarily intended to aid in navigation, the B-29's radar system could also be used for identification of ground targets (as radar systems on B-17s and B-24s had demonstrated in Europe). This technique was especially useful during periods of bad weather, when clouds obscured the target and the sight-dependent Norden bombsight was ineffective. Later B-29s were fitted with the more efficient AN/APQ-7 Eagle targeting radar and the AN/APN-4/9 Loran navigation systems.[19]

The remotely controlled defensive gunnery system put the B-29 in a class all its own.[20] This defensive system, designed by General Electric, included ten .50-caliber machine guns and one 20-millimeter (mm) cannon, which was mounted in the tail. The four computer-controlled machine gun turrets afforded control to more than one gunner; each gunner had a primary turret but could operate two turrets at the same time if necessary. The central gunner's section had a master gunnery panel that enabled the central fire control gunner to assign turrets to those gunners who had the best view of the target. Each gun had a sophisticated sighting mechanism that used incandescent light to sight targets. Gyroscopes and the fire control computer allowed the system to lead the target and provide the correct gun elevation to compensate for range.

The combined technological advances of the B-29 made it the weapon of choice for demonstrating the validity of high-altitude daylight precision bombardment. Army Air Force planners calculated that the mechanical combination of the doctrinal script with the B-29's advanced technology would equate to desired results. In the strategic environment of the Pacific theater, however, reality proved somewhat more complex and infinitely less predictable.



(US Air Force photo)

A Superfortress Over Japan. This B-29, flying from its base in the Marianas, is crossing Japan's Tama River near Tokyo.

Notes

1. For the evolution of airpower doctrine in the United States before World War II and the controversy between bomber and fighter advocates, see Thomas H. Greer, *The Development of Air Doctrine in the Army Air Arm, 1917-1941*, USAF Historical Study 89 (Maxwell AFB, Ala.: USAF Historical Division, Research Studies Institute, Air University, 1955). For a succinct account, see James Lea Cate, "Development of Air Doctrine, 1917–1941," *Air University Quarterly Review* 1, no. 3 (Winter 1947). For a more comprehensive study, see Robert Frank Futrell, *Ideas, Concepts, Doctrine: Basic Thinking in the United States Air Force, 1907–1984*, 2 vols. (Maxwell

AFB, Ala.: Air University Press, 1989). On the development of air doctrine within the context of the interservice debate, see James P. Tate, *The Army and Its Air Corps: Army Policy toward Aviation, 1919–1941* (Maxwell AFB, Ala.: Air University Press, 1988). Barry D. Watts, in *The Foundation of U.S. Air Doctrine: The Problem of Friction in War* (Maxwell AFB, Ala.: Air University Press, 1984), gives a short but critical analysis of the development of American airpower doctrine.

2. Robert F. Gass, *Theory, Doctrine, and Ball Bearings: Adapting Future Technology to Warfare* (Fort Leavenworth, Kans.: School of Advanced Military Studies, 1996), 12–15.

3. "The American observers (in England), in full knowledge of the British and German experience in the Battle of Britain, continued to place their faith in the heavily armed Flying Fortress and the Liberator, flying in great masses and in close defensive formations. Such force, in adequate mass and properly employed, they reasoned, would permit the precision daylight attacks so essential to American strategic air doctrine." Haywood S. Hansell Jr., *The Air Plan That Defeated Hitler* (Atlanta, Ga.: Longino & Porter, 1972), 33.

4. Gass, 4.

5. Tate, 158.

6. Ibid., 161–62. One notable exception was Capt Claire Chennault, later commander of the Flying Tigers in China, who disagreed with the bomber invincibility theory.

7. Ibid., 159.

8. Ibid., 164.

9. Hansell, 57.

10. Richard P. Hallion, "Prelude to Armageddon," *Air Power History* 42, no. 3 (Fall 1995): 42.

11. For the fateful story of the Consolidated B-32, see William T. Y'Blood, "Unwanted and Unloved: The Consolidated B-32," *Air Power History* 42, no. 3 (Fall 1995): 58–71.

12. For a bibliographic essay covering both primary and secondary sources on the development of the B-29 and B-29 operations in the Pacific, see Kenneth P. Werrell, *Blankets of Fire: U.S. Bombers Over Japan in World War II* (Washington, D.C.: Smithsonian Institution Press, 1996), 335–41. There is no centrally located holding of B-29 records and sources. Primary materials are maintained at various locations, including the National Archives in Washington, D.C., the Air Force Historical Research Agency at Maxwell AFB, Alabama, and the Boeing Company in Seattle. Most of the key players have written their own interesting, although often biased, accounts. These memoirs include Henry Harley "Hap" Arnold's, *Global Mission, 1886–1950* (New York: Harper, 1949); Curtis LeMay's *Mission with LeMay: My Story* (Garden City, N.Y: Doubleday, 1965) and *Superfortress: The B-29 and American Air Power* (New York: McGraw-Hill, 1988), and Haywood S. Hansell's *The Strategic Air War Against Japan* (Maxwell AFB, Ala.: Air University, 1980). Of the three authors, Hansell's account is the most

detailed and thoroughly analytic. Although not as extensively covered as the strategic air war over Europe, there are numerous secondary accounts available of B-29 operations against Japan. One of the most useful works is the official history by Wesley Frank Craven and James Cate, *The Army Air Forces in World War II* (Chicago: University of Chicago, 1948–58), though it is at times convoluted and poorly organized. For B-29 operations, see especially volume 5. Other worthwhile secondary works include Kevin Herbert's *Maximum Effort: The B-29s Against Japan* (Manhattan, Kans.: Sunflower University Press, 1983); E. Bartlett Kerr's *Flames Over Tokyo: The U.S. Army Air Forces' Incendiary Campaign Against Japan, 1944–1945* (New York: D.I. Fine, 1991); and Conrad C. Crane's *Bombs, Cities, and Civilians: American Airpower Strategy in World War II* (Lawrence, Kans.: University Press of Kansas, 1993).

13. Ronald H. Spector, *Eagle Against the Sun: The American War with Japan* (New York: Vintage Books, 1985), 488 ff.

14. Werrell, 57.

15. Hallion, 44.

16. For the story of the marriage of the Wright R-3350 engine to the B-29 Superfortress, see Robert E. Johnson, "Why the Boeing B-29 Bomber and Why the Wright R-3350 Engine," *American Aviation Society Historical Journal* 33, no. 3 (1988): 174–89. See also Werrell, 68–72, and Walter J. Boyne, *Clash of Wings: World War II in the Air* (New York: Simon and Schuster, 1994), 360.

17. Lee B. Kennett, *A History of Strategic Bombing* (New York: Scribner, 1982), 166.

18. Chester Marshall, *B-29 Superfortress* (Osceola, Wis.: Motorbooks International, 1993), 299.

19. Ibid., 301–3; Werrell, 195–201.

20. Marshall, 299–301; David A. Anderton, *B-29 Superfortress at War* (New York: Scribner, 1978), 24–31.

Chapter 4

Applying a Technological Solution

With the emergence of very long-range bombers, airmen had renewed confidence in the abilities of technology to fulfill the theoretical ends of bombing doctrine that had been developed "between the wars." Gen Henry H. "Hap" Arnold would later proclaim, "The combination of technical advances and the state of international relations . . . gave 'air power' a chance for mushroom growth."[1] The lack of VLR bomber availability, however, was still a limiting factor. Production schedules in 1941 suggested to planners that the B-29, the B-32, and the B-36 would not be available for several years; the weight of any early air offensive would rest primarily with the B-17 and the B-24. Only when the B-29 and the B-36 became available in greater quantities would they be given greater emphasis.[2] Originally, B-29 priority was scheduled for the European theater; AWPD-1 called for 12 groups of B-29s to operate from the Mediterranean basin, most likely to be stationed near Cairo, and another 12 groups to operate out of Northern Ireland.[3] Conditions changed, however, and the B-29s were deployed first to the Pacific theater.

After losing the backbone of the surface fleet at Pearl Harbor, the US Navy was no longer capable of performing the defensive duties initially envisioned for it by wartime planners.[4] European air planners now rightfully feared that "the bombers consigned to the strategic air war in Europe [to include the B-29] might be reassigned—or diluted in number—to meet emergency demands from the Pacific."[5] The first call for strategic bombing operations in the Pacific came as a result of the Casablanca Conference of January 1943. A remedy was needed for the desperate position of the Chinese government, and the Allies were unable to administer help in any other way. AWPD-42 was the first air plan to provide detailed planning for a strategic bombing campaign against Japan.[6] The Air War Plans Division prepared a plan in August 1943 for B-29s to operate from rear bases in India and forward bases in China against Japanese lines of communication and against Japan proper.

To conduct this campaign, the Joint Chiefs of Staff (JCS) created an entirely new organization: Twentieth Air Force. It would operate under the command of General Arnold, commanding general, Army Air Forces (AAF). At Cairo in late November 1943, the Combined Chiefs of Staff adopted a "grand strategy "statement that included a significant change of wording as recommended by General Hansell, the AAF's chief planner. The change read, "Our studies have taken account of the possibility that invasion of the principal Japanese islands may not be necessary and the defeat of Japan may be accomplished by sea and air blockade and intensive air bombardment from progressively advanced bases."[7] Airpower was no longer a supporting arm in the Pacific.

The limitations of strategic airpower doctrine were further exposed in operations like the disastrous Schweinfurt raids in late 1943,[8] but perhaps nowhere more clearly than in AAF operations from India and China known as Operation Matterhorn. The first attacks against Japanese targets by the newly formed XX Bomber Command in China under Twentieth Air Force did not occur until June 1944, nearly a year after the Operation Matterhorn concept was born.

An AAF Committee on Operational Analysis initially identified six Japanese targets on 11 November 1943:

1. Merchant shipping, both in Japanese harbors and at sea.
2. Steel production facilities, particularly coke oven plants.
3. Urban industrial areas.
4. Aircraft plants.
5. Ball bearing plants.
6. Japan's electronics industry.[9]

Due to friction generated by distance, weather, mechanical bugs, and the underappreciated difficulties of logistically supporting the operation, the impacts of Matterhorn upon this target set did not live up to the airpower theorists' predictions.[10] Logistical difficulties limited the results and made them extremely costly. To get one B-29 over a Japanese target, seven other B-29s carried bombs and gasoline from India to allow the mission to occur.[11] At its peak, XX Bomber Command could manage only two sorties per month per aircraft—and only one-half of those sorties were directed against the main islands of Japan.[12] Initiated in part to meet political exigencies in China, Operation Matterhorn was nevertheless limited by military realities—realities that proved beyond the adaptive capabilities of both operators and planners.[13] The last of the Matterhorn missions occurred in March 1945 as bases for the B-29 were shifting to the central Pacific.

The Mariana Islands in the central Pacific offered airpower advocates a viable alternative to Operation Matterhorn. On 12 March 1944, the JCS issued a strategic directive instructing Adm Chester Nimitz to conduct the invasion of the Marianas in Operation Forager, thus enabling a new range of airpower possibilities.[14] Operating from Saipan, just 1,200 miles from Tokyo, the B-29s could attack the home islands of Japan more effectively than from Chinese bases.[15] Saipan was one of three islands large enough to support air and naval bases; the other two were Tinian, a few miles south of Saipan, and Guam, the southernmost island. Guam had been an American possession before it was lost to the Japanese in 1941. With the brutally costly capture of Saipan, Tinian, and Guam in the summer of 1944, at precisely the same time B-29s were just beginning to launch ill-fated raids from bases in China, a window of opportunity opened for the AAF. Engineers followed closely behind the invasion forces to expand and improve the islands' airfields in preparation for B-29 operations.[16] By 24 June, even before the fighting had ended on Saipan, the first B-29 airfield was under construction.[17] Generals Hansell and Wolfe flew the first B-29 to arrive at Saipan. It arrived on 12 October 1944.

Control of the B-29s in the Marianas fell under the newly created XXI Bomber Command of Twentieth Air Force. Haywood Hansell was the XXI's first commander. The new command's crews flew their first combat mission on 28 October 1944. The XXI's first missions from the Marianas were training missions against the island of Truk and relatively low-risk missions against Japanese positions on the island of Iwo Jima. These missions were designed to build the crews' experience and allow them to learn about the operational environment. Their first mission against the home islands, flown for both psychological and military reasons against the Nakajima aircraft plants in Tokyo, took place on 24 November 1944. In that initial attack on Japan's home islands, 111 B-29s were airborne for more than 13 hours.[18]

Like those in Operation Matterhorn, B-29 raids from the Marianas were not without difficulties. The attack against the Nakajima aircraft plants in November 1944 was typical of the first attempts at precision bombardment against Japanese industry from the Marianas. The raid was cancelled five times over a two-week period due to poor weather over the target. Of the 111 B-29s that participated in the attack, 17 aborted before reaching Japan and six were unable to bomb because of mechanical difficulties. The attacking bombers encountered 120-knot winds at altitude while overcast cloud layers almost completely obscured the target area. Of the 88 airplanes that bombed the area surrounding the plant, 35 had to do so by radar. In the end, only 48 bombs fell in the factory area, damaging one percent of the building and 2.4 percent of the machinery while injuring or killing 132 people in the factory complex. Two B-29s were lost over the target.[19]

When XXI Bomber Command failed to deliver "the destructive potential inherent in the B-29,"[20] General Arnold removed General Hansell on 20 January 1945 and replaced him with Gen Curtis E. LeMay.[21] With a burly physique and a hard-nosed reputation, LeMay was arguably well suited for the job.[22] LeMay had established a distinguished record as a bomber commander in Europe and the 37-year-old general had become a favorite B-29 troubleshooter for Arnold; earlier, Arnold had named LeMay to replace Gen Kenneth Wolfe as commander of XX Bomber Command for B-29 operations from China. Now hoping to reverse the poor performance of operations from the Marianas, he turned to LeMay once again. As commander of XXI Bomber Command, LeMay was a principal player in shaping the operational, strategic, and tactical adaptations required to overcome the uncertainties that emerged as the B-29s were deployed against Japan.

Notes

1. Henry Harley Arnold, *Global Mission* (New York: Harper, 1949), 158.
2. Haywood S. Hansell Jr., *The Air Plan That Defeated Hitler* (Atlanta, Ga.: Longino & Porter, 1972), 48.
3. Ibid., 54.
4. William Green, *Famous Bombers of the Second World War* (Garden City, N.Y.: Hanover House, 1969).
5. Kenneth P. Werrell, *Blankets of Fire: U. S. Bombers Over Japan During World War II* (Washington, D.C.: Smithsonian Institution Press, 1996), 49–50.
6. Richard P. Hallion, "Prelude to Armageddon," *Air Power History* 42, no. 3 (Fall 1995): 38–54.
7. Martin W. Bowman, *USAAF Handbook 1939–1945* (Mechanicsburg, Pa.: Stackpole Books, 1997), 256.
8. Richard G. Alexander, "Experiment in Total War," in United States Naval Institute *Proceedings* 2, no. 8 (August 1956): 844.
9. Wesley Frank Craven and James Cate, *The Army Air Forces in World War II*. 7 vols. (Chicago: University of Chicago Press, 1948–1958), 13–31.
10. Ibid., 13–31; Werrell, 101–2.
11. Winton Close, "B-29s in the CBI – A Pilot's Perspective," *Aerospace Historian* 30, no. 1 (1983): 13.
12. Ronald H. Spector, *Eagle Against the Sun: The American War with Japan* (New York: Free Press, 1985), 491.
13. Hallion, 44–48.
14. Ibid., 45.
15. Russell F. Weigley, *The American Way of War: A History of United States Military Strategy and Policy* (New York: MacMillan Publishing Co., Inc., 1973), 290.
16. Lee B. Kennett, *A History of Strategic Bombing* (New York: Scribner, 1982), 166.
17. Hallion, 45.
18. Ibid., 50.
19. Alexander, 844.
20. Hansell, 211.
21. Victor Davis Hanson, "The Right Man," in *Military History Quarterly* 8, no. 3 (Spring 1996): 56–65.
22. Close, 8.

Chapter 5

Uncertainty and Unintended Consequences

A veil of uncertainty is the one unvarying factor in war.

—Erich von Manstein

The B-29 was best known for its technological advances in engines, pressurization, and remotely controlled defensive armament. It was these technological advances that gave the B-29 the capabilities to accomplish the doctrinally designated role of unescorted strategic bombardment at high altitude. It was, however, precisely these advances that gave both engineers and crew members the greatest difficulty. The hasty development of the B-29 (it went from conceptual designs to operational missions in five years) resulted in numerous "bugs"; extensive technological adaptations were required to overcome them.

The Wright R-3350 was renowned not only for its power, but also for the high incidence of engine fires.[1] In fact, an in-flight fire that originated in the engines had caused the loss of one of the two XB-29 prototypes and its entire crew.[2] One-fifth of all B-29 accidents between February 1943 and July 1945 were caused by engine fires. Once a fire started in an engine, it was very difficult to put out; the carbon dioxide fire extinguisher system was inefficient, and several engine components were made of highly flammable magnesium. Engine fires were the biggest fear of B-29 crews.[3]

The need for pressurization to perform high-altitude missions competed with doctrinal demands for robust, remotely controlled defensive armaments—and both were technologically challenging requirements. Arnold noted that pressurization was "one of the biggest early headaches."[4] Early problems with pressurization forced practice bombing to be carried out from 15,000 feet instead of the prescribed altitude of 30,000 feet.[5] Problems included rapid depressurization if there was a rupture of the pressurized compartments (a gunner's worst fear: he might be swept from the aircraft should his sighting blister fail) and window frosting at high altitudes. Despite several modifications, which included such items as cockpit fans, gas heaters, and flexible ducts, these problems would persist throughout the war.[6]

The remotely controlled defensive systems, which were extremely heavy, used nonretracting gun turrets that increased drag while decreasing the speed, range, and endurance of the aircraft. One adaptation required by the nonretractable turrets was the addition of a "tailskid" to keep pilots from grinding off the aft lower turret when making high-angle takeoffs.[7] Airmen at Eglin Air Proving Ground complained that maintaining the remotely controlled system was a difficult process. They also said the system was vulnerable and inherently inaccurate. The final report of the Eglin staff concluded, "the defensive armament of the B-29 airplane is not suitable for a series of unescorted combat operations in theaters where the airplane will be subjected to more than brief, desultory fighter attacks."[8]

Despite the vulnerability and inaccuracy of the system, and despite aircrew preference for locally controlled gun turrets, the General Electric remotely controlled defensive system was selected for the B-29 because it made the problem of pressurization easier for Boeing designers to resolve.[9] Concerns about the inadequacies of the defensive system eventually drove decision makers toward night missions instead of daylight raids. Bombing was less accurate, but few Japanese fighters could effectively operate at night; precision bombing could be more effective during daylight hours, but the B-29s were then vulnerable to Japanese fighters.[10]

These robust defensive systems had another important unintended consequence. Flying in relatively tight formations, the B-29s were highly susceptible to incidents of friendly fire. This vulnerability encouraged the removal (at least for a time) of defensive armaments and the change in tactics from formation bombing to single aircraft flying sequentially over the target.[11]

Although frequently intended to be labor-saving measures, new systems often demand more training time and manpower to physically and intellectually process the added technological complexity. The B-29 experience serves as a case in point.

It was the first operationally employed aircraft to require a flight engineer among the crew positions. Facing rearward behind the pilot, the B-29's flight engineer was responsible for monitoring and regulating the aircraft's systems. Pilots were initially reluctant to accept this situation, since it meant that many of the controls would be out of their sight and reach.

The flight engineer position was also difficult to fill, since only previously trained officer mechanics were accepted into the flight engineer school. Later, as demand grew, the AAF accepted enlisted mechanics. In fact, about one-half of the flight engineers in this essential crew position during combat operations were noncommissioned officers. In an act of desperation to cover unfilled manning requirements, AAF even recruited pilots for the position of flight engineer. The requirement for a flight engineer to serve aboard the B-29, vital for successfully completing long-range missions in the technologically complex aircraft, created additional manpower and training requirements.[12]

The technological complexity of the B-29 led to increased manning requirements as well as additional training requirements for other crew positions. Its design was so radically new that it required exclusively designed courses for each of its components. Radar operators, for example, had no experience with advanced radar systems. Even after July 1944 when radar equipment was plentiful enough to begin training, there were not enough qualified instructors to carry it out. Furthermore, few of the operators trusted the radar—and the Kansas plains were ill suited to demonstrate its value.[13] Pilot training was complicated early in the program by the lack of airframes. Aircrews were initially forced to use other aircraft for training; for example, the crews that would be the first to man the B-29s actually trained in the twin-engine Martin B-26.[14] Despite valiant efforts by all involved, the B-29 crews initially operating out of the Marianas averaged fewer than 100 hours of B-29 flying time and fewer than 12 hours flying in high-altitude formations.[15]

Unknown factors and unanticipated phenomena in the operating environment were also sources of "Clausewitzean friction" in B-29 operations. Hansell described the weather over

Japan as "our most implacable and inscrutable enemy."[16] Weather was so poor, especially during the winter, that there were sometimes only three or four good bombing days a month. Obtaining accurate weather forecasts for the Japanese mainland presented a major challenge. For various reasons, weather analysis and prediction were not as reliable in the Pacific as in Europe—and weather forecasting was most critical during the first months of B-29 operations. With only one runway in operation on Saipan, a weather divert or a crashed B-29 on Isley Field might spell disaster for those still airborne.

Even more important operationally, B-29 planners and strategists, who advocated high-altitude precision bombing, failed to account for the effects of the jet stream. Aircrews soon learned that bombing accuracy and aircraft performance were significantly affected by it.[17] Crews operating at 25,000 feet and above often found the river of air flowing from west to east at speeds above 200 miles per hour. Flying downwind caused ground speeds exceeding 450 knots, far greater than optimum for accurate precision bombing either visually or by radar. Flying against the jet stream reduced the range of the bombers and left them vulnerable to enemy air defense for longer periods of time. On one mission flown upwind to increase bombing accuracy, aircrews reported flying backward along the ground as wind speed exceeded their true airspeed.[18] In the absence of accurate forecasts, the only recourse was to fly at lower altitudes where the jet stream was not as strong.

Beyond the uncertainties of employing the B-29, its presence introduced unintended consequences for both friendly and enemy systems. One unintended consequence for the friendly military system was further strain on the already convoluted command relationships in the Pacific. The B-29s were placed under the direct control of General Arnold, AAF commander in chief in Washington.[19]

In China, both Gen Claire Chennault and Gen Joseph Stilwell demanded operational control of resources dedicated to the B-29 for Operation Matterhorn—especially after the renewed Japanese *Ishigo* offensive in China in 1944. Gen Douglas MacArthur, through his air commander Gen George Kenney, advocated using the B-29s in the southwest Pacific. Kenney argued that the B-29s should operate from bases in northern Australia in support of his island-hopping thrust toward the Philippines.[20]

The Navy, perhaps rightly so, feared that its central Pacific thrust toward Formosa would be subordinated to the strategic bombardment of Japan.[21] One member of Adm Ernest King's staff noted, "The interests of the AAF and the Navy clash seriously in the Central Pacific campaign. The danger is obvious of our amphibious campaign being turned into one that is auxiliary support to permit the AAF to get into position to end the war."[22] Dual-hatted as commanding general of Army Air Forces and commander of Twentieth Air Force, General Arnold did not answer to Pacific theater or area commanders; he was coequal with the other joint chiefs, responsible in essence only to General Marshall and President Roosevelt.[23] Had the Navy followed Army's lead and placed the Tenth Fleet directly under Admiral King, effective unified action in the Pacific might have been well nigh impossible.

In effect, command arrangements ranked the B-29 strategic campaign against Japan over all other efforts in the Pacific theater. In the last month of the war, after the artificial area boundaries between MacArthur and Nimitz had become obsolete, Pacific command was equally divided between the Army under MacArthur, the Navy under Nimitz, and the Strategic Air Force under Gen Carl Spaatz. Although still technically owned by the Army, the strategic bombardment force was in a position of near equality with the Army and Navy.[24] The introduction of the B-29 enlivened tension between the services and added complexity to the command structure in the Pacific.

The employment of B-29s from the Marianas, in a dance of coevolution, also affected Japanese military developments. The Japanese understood the dangers posed by American B-29s operating from these islands. Lt Gen Yoshitsugu Saito, the Japanese defender of Saipan, wrote, "the fate of the Empire will be decided in this one action."[25] Stiff Japanese resistance in the Marianas, and later on Iwo Jima, was due in part to this realization. The construction of Isley Airfield on Saipan triggered increased Japanese reconnaissance sorties and aircraft attacks staged through Iwo Jima. Although kept generally under control by the combination of antiaircraft artillery and Northrup P-61 Black Widow fighters, these Japanese attacks did cause some damage. On 27 November 1944, for example, four B-29s were destroyed and 28 others damaged by a Japanese attack. Altogether, Japanese raiders destroyed eleven B-29s, heavily damaged eight, and less seriously damaged 35 others. The raids also killed 45 Americans and wounded 200 others at a cost to Japan of 37 aircraft lost.[26] In its turn, the Japanese response to the employment of B-29s from the Marianas would shape the evolution of American actions.

Notes

1. Richard P. Hallion, "Prelude to Armageddon," *Air Power History* 42, no. 3 (Fall 1995): 44; Haywood S. Hansell Jr., *The Air Plan That Defeated Hitler* (Atlanta, Ga.: Longino & Porter, 1972), 203–4.

2. Kenneth P. Werrell, *Blankets of Fire: U. S. Bombers Over Japan During World War II* (Washington, D.C.: Smithsonian Institution Press, 1996), 71.

3. Ibid., 64.

4. Ibid., 124.

5. Ibid., 64.

6. Ibid., 66.

7. "Tests Relative to the Defense and Tactical Use of the B-29." Memorandum from the Operational Analysis Division, Department of Physics, University of New Mexico, 15 November 1944 (Maxwell AFB, Ala.: Air Force Historical Research Agency, 760.310–3.)

8. Being less technologically complex, locally controlled turrets were considered more accurate and more easily maintained. Remotely controlled turrets made pressurization easier because they were smaller and needed no pressurization if no gunner was physically manning the guns.

9. Werrell, 63–68.

10. Ibid., 155.

11. Ibid., 61–62.

12. Ibid., 123–24.

13. Ibid., 92.

14. Hallion, 50; David A. Anderton, *B-29 Superfortress at War* (New York: Scribner and Sons, 1978), 35–36.

15. Haywood S. Hansell Jr., *The Air Plan That Defeated Hitler* (Atlanta, Ga.: Longino & Porter, 1972), 203.

16. Hallion, 51.

17. Ronald H. Spector, *Eagle Against the Sun: The American War with Japan* (New York: Free Press, 1985), 493.

18. Hallion, 44–45.

19. Stanley L. Falk, "General Kenney, the Indirect Approach, and the B-29s," *Aerospace History*, 1981, 147–55.

20. Russell F. Weigley, *The American Way of War: A History of United States Military Strategy and Policy* (New York: MacMillan Publishing Co., Inc., 1973), 285.

21. Spector, 492.

22. Ibid., 489–90, 225; Henry Harley Arnold, *Global Mission* (New York: Harper, 1949), 548–49; Jeffrey S. Underwood, *The Wings of Democracy: The Influence of Air Power on the Roosevelt Administration, 1933–1941* (College Station, Tex.: Texas A&M University Press, 1991).

23. Louis Morton, *Pacific Command: A Study in Interservice Relations*, Harmon Memorial Lecture in Military History, United States Air Force Academy, 1961, 150.

24. Hallion, 45.

25. Ibid., 49.

26. Hansell, 30.

Chapter 6

Technological and Operational Adaptation

Improvisation is the natural order of warfare.
The perfect formulas will continue to be found only on charts.

—S. L. A. Marshall

Effective and timely adaptation requires learning about the operating environment. Learning about the operating environment for the employment of airpower was the mission of the Air Intelligence Services. First formed in 1940 by Haywood Hansell and Tom White at the request of General Arnold, the Strategic Air Intelligence Section (SAIS) consisted of a system of assistant military attachés for air at US embassies around the world and an analysis branch at the Pentagon. Its focus included the composition of foreign air forces, the infrastructure (airports and air bases) to support those forces, and the economic-social-industrial analysis of major foreign powers.[1] Although relatively successful at collecting information about Germany and Italy, the SAIS was not able to gather much detailed information on Japan. That island nation was surrounded by a "curtain of secrecy" as well as by the Pacific Ocean. Hansell claimed there were not even any recent maps available to air planners.[2] The Army Air Force in the Pacific would learn through its own experience under the inevitable stress of war.[3]

Surprisingly, the AAF did not take advantage of one of its best sources of operational learning: wartime experience gained from the European bombing campaign. Although the AAF in the Pacific would employ methods that came to closely resemble the night fire raids of the Royal Air Force (RAF) in Europe, there is no evidence of any shared learning between the two. The United States Strategic Bombing Survey, which was intended for use in the Pacific war, arrived too late to influence its conduct.[4] Stumbling through to a suitable solution, the AAF in the Pacific neglected sources of learning that might have identified many uncertainties and aided successful adaptation. On its own, the strategic air war in the Pacific evolved toward the British concept of bombing used in Europe.

Thus, the AAF adapted operationally to the uncertainties initially posed by employment of the B-29 in the Pacific by switching from high-altitude daylight precision bombardment raids against critical industrial nodes to low-altitude night incendiary attacks against Japanese cities.

The turning point came in March 1945, when the commander of XXI Bomber Command, General LeMay, switched exclusively to low-altitude attacks intended to "burn out" major Japanese cities.[5] The change to incendiary attacks resulted in part from poor performance during conventional high-explosive missions against precision targets. Despite the promises of accuracy from the new technology, the results of radar bombing with the B-29's new AN/APQ-13 radar bombsights were disappointing.

The new tactic was not an act of desperation, but a well-considered adaptation first suggested by air strategists before the war. In his 1937 study, "Japan as an Objective for Air Attack," Capt Thomas D. White of the Air Corps Tactical School noted, "Large sections of Japanese cities are built of flimsy and highly inflammable materials. The earthquake disaster of 1924 bears witness to the fearful destruction that may be inflicted by incendiary bombs."[6] Even Adm Isoruku Yamamoto had pointed out this vulnerability as early as 1939: "Cities made of wood and paper would burn easily. The army talks big, but if war comes and there were large-scale air raids, there is no telling what would happen."[7] Japanese fire-fighting equipment was primitive and inadequate for the disaster that was about to befall Japanese cities. The nature of targets in Japan was different from those in Germany; Japanese industry, more widely dispersed within Japanese cities, was less vulnerable to precision attack. The cities themselves, however, were extremely vulnerable to fire bombing.[8]

Prior to 1945, strategists in Washington, including Arnold, had pressed for incendiary attacks, but both Hansell and LeMay opposed them. They favored doctrinally conventional precision bombardment.[9] Hansell's preference for precision bombardment would, at least in part, cost him his job in the end.[10] Motivations to move away from precision attacks included the cost of unescorted daylight missions due to Japanese fighters and antiaircraft fire, the vulnerability of Japanese cities, and the failures of pinpoint bombing raids against Japanese industry.[11] Still, it was not until December 1944 that LeMay, then commanding XX Bomber Command in China, launched the first incendiary raid—against the Chinese city of Hankow.[12] However, since incendiaries had proven relatively difficult to deliver from 30,000 feet during testing and evaluation, B-29 crews continued to use high-altitude conventional attacks after the Hankow raid. These difficulties in accurately dropping incendiaries from high altitudes led to attacks at lower altitudes. Flying at lower altitudes also avoided the unpredictable navigation and bombing effects of the jet stream—and it reduced engine wear from the high-power climb to altitude, thereby improving engine reliability.

The M69, a more explosive incendiary introduced by the Army's Chemical Warfare Service, made incendiary attacks potentially even more lethal.[13] An encouraging test incendiary raid against Tokyo on 25 February 1945 resulted in the complete burning of about one square mile of the city.[14] One massive raid in March burned some 16 square miles of Tokyo—about 18 percent of the city's industrial area and 63 percent of its commercial area.[15] The only major limiting factor in incendiary operations was the supply of napalm bombs; these weapons were in such demand toward the end of the war that supply crews would drive them directly from supply ships to bombers waiting on the airfields.[16] Incendiary raids at low altitudes essentially overwhelmed Japan's ability to adapt defensively.

To facilitate larger bomb loads, LeMay stripped the B-29s of guns and ammunition. Since the B-29 normally carried 1½ tons of armament, this adjustment represented a significant increase in bomb load capacity.[17] The decision to "strip the guns and add the bombs" was spurred not only by the desire for more destructive effects on Japanese targets, but also by the absence of Japanese night fighters. Although removing the B-29's defensive systems was efficient tactically, it had unpredictable and unintended negative effects on crew morale. Despite the lack of Japanese fighter opposition, crew members were unwilling to fly without a defense system and the guns were once again installed on the B-29s.[18]

One other adaptation to defensive systems that resulted from combat experience was the removal of the 20-mm tail gun and the addition of two more .50 caliber machine guns to the forward upper turret. This change was implemented because Japanese fighters preferred head-on attacks against the fast bombers.[19] A simple mechanical cam follower was also included on the forward upper turret to prevent gunners from shooting off parts of their own airplane—a worst-case fratricide.[20]

The taking of Iwo Jima by US forces was a strategic adaptation facilitated by the presence of B-29s. US occupation of the island provided several benefits to B-29 operations.

1. Japanese radar outposts on the island were eliminated.
2. The threat of Japanese fighters operating from Iwo Jima against B-29 bases in the Marianas was removed.
3. The distance to Japanese targets was shortened and navigation was improved when B-29s could freely fly over Iwo Jima.
4. Airfields could be provided on the island for emergency B-29 recovery and for staging deeper strikes against Japan.[21]

Although the Marines did not declare the island secured until 26 March, a B-29 made the first emergency landing on Iwo Jima three weeks earlier, on 4 March. The bomber was returning from a raid against Japan. While the cost of taking the island was enormously high, the operation potentially saved as many as 22,000 crew members from the 2,251 crippled B-29s that landed at Iwo Jima. Without use of the island as an emergency recovery area, those crew members might have had to ditch and been lost at sea.[22]

Iwo Jima also could serve as a base for escort fighters to accompany the B-29s on their raids into Japan, an adaptation dictated in part by deficiencies in the B-29's defensive systems. Ironically, by the time sufficient numbers of long-range escorts were available and a base at Iwo Jima was ready to accept them, the escorts were no longer needed. The Japanese air force no longer posed any real threat, given its virtual absence from the scene. Instead, these long-range US fighters proved more useful to the strategic air war by serving in the ground attack role against various Japanese targets.[23] Although changes in the tactical situation lessened the importance of Iwo Jima toward the end of the war, its value to the strategic air campaign must not be underestimated.[24]

Another strategic and operational adaptation of the B-29 was its use as a mine-laying instrument to blockade Japanese sea lines of communication.[25] The first of the B-29 mining operations occurred as early as August 1944 against Japanese lines of communication in the southwest Pacific, but the B-29s of Twentieth Air Force did not launch a sustained mining campaign until January 1945. Although the initial Army Air Force response to the Navy-sponsored mining plan was negative, aerial delivery of mines proved to be an effective use of the B-29 when weather prohibited bombing operations. LeMay eventually favored mine-laying missions for the B-29s. In Operation Starvation, Twentieth Air Force B-29s sowed some 12,000 naval mines.[26] US submarine attacks, which were aided by the aerial dropping of mines, were devastating to the Japanese economy—perhaps decisively so. By 1945 Japan had lost nine million of its ten million tons of merchant shipping.[27] According to Japanese records, the aerial mining campaign accounted for 63 percent of all Japanese merchant shipping losses during the final six months of the war.[28]

In the closing days of the war, XXI Bomber Command came up with yet another operational use for the B-29: dropping leaflets on Japanese cities to warn the civilian populace that further attacks were forthcoming. By dropping these leaflets, the B-29s disrupted Japanese production, lowered morale, and encouraged civilians to replace the current Japanese leadership. Beginning on 27 July, the leaflet drops were followed by shortwave broadcasts.[29] By the end of the war, the B-29s had scattered some 4,500,000 leaflets over Japanese cities.[30]

To overcome the uncertainties of weather, American crews relied almost exclusively upon nightly B-29 reconnaissance flights toward Japan. Aircrews in Europe had depended a great deal on Ultra intelligence reports for weather information, but Hansell and LeMay had assumed that this type of information was unavailable for the Pacific theater. Unfortunately, as Hansell and others would learn 30 years after the war, Allied intelligence agents in Australia had been receiving Japanese weather reports throughout the war but had not passed this information along.[31] Put in the context of complexity theory, lack of shared learning about the operational environment prohibited effective adaptation.

In addition to strategic and operational adaptations, technical, mechanical, and procedural adaptations were necessitated by simultaneous problems in production, training, and employment. To improve mechanical reliability and overcome the uncertainty associated with the complex technology of the B-29, LeMay changed from "crew chief" maintenance to "production line" maintenance. Instead of being responsible for maintenance of the entire aircraft and all of its systems, individual specialists were now responsible for separate components on the B-29. This system eased the problems created by a shortage of maintenance personnel and the lack of adequate maintenance training.[32] The result was more aircraft in commission, fewer aborts, and a greater percentage of aircraft bombing their primary targets. A secondary effect, however, had negative implications: crew stress and flying fatigue increased, severely affecting flight crew morale—thanks to the improved aircraft reliability rates.[33]

Avoiding engine fires involved a combination of mechanical fixes and changes in crew technique. Later models of the B-29 included shortened cowl flaps and improved lubrication to reduce the chances of engine fire. New cowl flaps, ducted baffles to better circulate air, and oil crossover tubes to better circulate oil were installed at the Oklahoma City Air Depot beginning in September 1944. Later that year, those modifications were packed in kits and sent to combat forces in the field.[34] To minimize overheating of the huge engines during ground takeoff run, crews ignored technical order takeoff speeds and used the entire length of runway to achieve maximum ground speed. This maneuver increased engine cooling before the aircraft became airborne by increasing airflow over the engines.[35] The result of these adaptations was that engine temperatures were kept below designated limits and engine life began to increase.[36]

Another adaptation required the development of a logistical structure to support B-29 operations from the Marianas. Lt Gen Millard F. Harmon was primarily responsible for its development. To centralize logistical and administrative responsibility for all AAF forces in the central Pacific, Harmon was appointed deputy commander of Twentieth Air Force and commander of the AAF Pacific Operations Area when the Twentieth was activated on 1 August 1944.[37] Harmon's direct personal effort was responsible for bringing the runway construction effort on the Marianas up to speed after it had fallen behind original planning schedules. Despite the 8,000 miles back to the air logistics center in Sacramento, California, and direct competition with the Navy for resources, supply problems never affected operations as seriously as they had in the China-Burma-India theater.[38]

Successful adaptation required the energetic intervention of key individuals throughout the process, including not only Curtis LeMay but also Hap Arnold. When delays pushed the initial operations date back from the summer of 1943 to the spring of 1944, Arnold made an inspection trip to the Boeing production facility in Wichita and the B-29 training base at Salina, Kansas.

> I was appalled at what I found there. There were shortages in all kinds and classes of equipment. The engines were not fitted with the latest gadgets, the planes were not ready to go. It would be impossible for them to be anywhere near China by the 15th of April unless some drastic measures were taken.[39]

Arnold's "drastic measures" included an intensive six-week modification and upgrade effort that became known as the "Battle of Kansas." It would take a personal visit by Arnold to the island of Guam in June 1945 to overcome command and logistical disputes with the Navy.[40] One unintended consequence of Arnold's energetic interventions was a series of heart attacks in 1944 and 1945 that ruined Arnold's health.[41] Before Haywood Hansell was removed from command, Arnold also took several steps to improve B-29 aircrew training. These actions included providing additional in-theater training for combat crews and establishing a school for lead crews.[42] Adaptation was not the result of fortuitous chance, but of human vision and the will and energy to follow through.

Notes

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3. Kenneth P. Werrell, "The Bombing of Japan: Three New Insights" (unpublished paper, Maxwell AFB, Ala.: Center for Aerospace Doctrine, Research and Education), 1999.

4. Ibid.

5. Ronald H. Spector, *Eagle Against the Sun: The American War with Japan* (New York: Free Press, 1985), 503–6.

6. Thomas D. White, "Japan as an Objective for Air Attack," paper for the Intelligence Section, Air Corps Tactical School, Maxwell Field, Ala., 1937–38 (Maxwell AFB, Ala.: Air Force Historical Research Agency [AFHRA]), 248.501-65B.

7. Ed Whitcomb, *On Celestial Wings* (Maxwell AFB, Ala.: Air University Press, 1995), 134.

8. Lee B. Kennett, *A History of Strategic Bombing* (New York: Scribner, 1982), 164.

9. Werrell, 6.

10. Kennett, 168–69.

11. Richard G. Alexander, "Experiment in Total War," in United States Naval Institute *Proceedings* 2, no. 8 (August 1956): 845.

12. Hansell; Claire S. Chennault, *Way of a Fighter* (New York: Putnam, 1949), 330.

13. Spector, 491–92; Walter J. Boyne, *Clash of Wings: World War II in the Air* (New York: Simon and Schuster, 1994), 370–71.

14. Alexander, 845.

15. Ibid.; Whitcomb, 134.

16. Victor Davis Hanson, "The Right Man," in *Military History Quarterly* 8, no. 3 (Spring 1996): 60.

17. Kennett, 170.

18. Hanson, 59.

19. David A. Anderton, *B-29 Superfortress at War* (New York: Scribner and Sons, 1978), 24–25; Werrell, 145; Edwin Hewitt, memorandum, "Report for Operations Analysis Division, 20th Air Force, 23 December 1944" (Maxwell AFB, Ala.: AFHRA), 760.310-3.

20. Anderton, 31.

21. Edward R. Lightfoot, memorandum, subject: Operation Workman, staging VLR strikes through Iwo Jima, 17 January 1945, Maxwell AFB, Ala., AFHRA, 762.322-2; Lotha A. Smith, memorandum to Chief of Staff, 20th Air

Force, subject: Progress Report of Plans for Utilization of "Workman," 1 March 1945, Maxwell AFB, Ala., Air Force Historical Research Agency, 761.322-1.

22. Whitcomb, 136.

23. *United States Strategic Bombing Surveys (European War) (Pacific War)* (Reprint, Maxwell AFB, Ala.: Air University Press, 1987).

24. Wesley Frank Craven and James Cate, *The Army Air Forces in World War II*. 7 vols. (Chicago: University of Chicago Press, 1948–1958), 597–98.

25. Ibid., 662–73; Werrell, 170–77.

26. Kennett, 174.

27. J. C. Wylie Jr., "Reflections on the War in the Pacific," United States Naval Institute *Proceedings* 78, no 4 (April 1952): 351–61.

28. Kreis, 345.

29. Werrell, 202–3.

30. Kennett, 174.

31. Richard P. Hallion, "Prelude to Armageddon," *Air Power History* 42, no. 3 (Fall 1995): 51; Hansell, 203–4.

32. Werrell, 146–47.

33. Ibid., 166–67.

34. Ibid., 70.

35. Winton Close, "B-29s in the CBI – A Pilot's Perspective," *Aerospace Historian* 30, no. 1 (1983): 8.

36. Werrell, 70.

37. Hallion, 48–49.

38. Craven and Cate, xvii.

39. Close, 44.

40. Thomas M. Coffey, *Hap: The Story of the United States Air Force and the Man Who Built It, General Henry H. "Hap" Arnold* (New York: Viking, 1982), 367.

41. Ibid., 358.

42. Werrell, 136.

Conclusion

The war was lost when the Marianas were taken away from Japan and when we heard the B-29s were coming out. We had nothing in Japan that we could use against such a weapon. From the point of view of the Home Defense Command, we felt that the war was lost and we said so. If the B-29s could come over Japan, there was nothing that could be done.

—Prince Higashikuni
Commander in Chief
Home Defense Headquarters

Given the costs of modern military technology, there is a duty for military strategists to study its application and use it wisely. This statement is especially true for airpower strategists. Airpower and technology are integrally and synergistically related. An understanding of airpower and its place in national strategy requires an understanding of the efficient application of technology in warfare. As demonstrated by the American experience with the Boeing B-29 Superfortress, efficient application of military technology requires an appreciation for the inevitably of uncertainty in war and the need for adaptation to these inevitable uncertainties. Military planners should not avoid new technologies because of the increased complexity that they represent. Instead, they should acknowledge the new demands that increased complexity encompasses, and they should allow for flexibility and adaptation in the use of military technology. Technology and military strategy should be fully integrated so commanders can conduct the kinds of campaigns and military operations that offer the best chance for success in achieving the nation's political and military objectives.

One finding from the study of B-29 operations in the Pacific through the lens of complexity theory is that the Japanese failed to adapt defensively to American offensive adaptations. Similar to the American neglect of British experience, but to a greater degree, the Japanese failed to learn from German successes against the European air campaign. Unlike the Germans, the Japanese did not disperse their industries until it was too late—and they did not organize a credible air defense. The Japanese did not acquire German radar technology, but instead used British and American radars captured during the first years of the Pacific war. What little adaptation the Japanese did show (such as concentrating fighters and flak around probable targets and creating "aerial Kamikazes" by ramming American bombers) was uncoordinated and not widely adopted. In response to the threat of aerial and naval Kamikazes

The Japanese theater presented uncertainties and unintended consequences that required adaptations by each of the services. The Army shaped itself into an image of the Marines, learning the demands of island warfare. The Navy evolved from the battleship to the aircraft carrier and from "Mahanian" decisive engagements to submarine warfare aimed at strangling the enemy into submission. The Air Force and the B-29 were not alone in the need for adaptations of strategy, operational methods, and tactical devices in the Pacific theater.

Adaptation is required to solve the problems created by uncertainty—and war is filled with uncertainty. The uncertainties presented by the introduction of the B-29 to the Pacific theater included mechanical malfunctions, doctrinal shortcomings, and unintended consequences within the military environment in the Pacific. Overcoming these uncertainties required extensive technical, operational, and strategic adaptations.

Despite the difficulties it presented, the B-29 proved to be a successful instrument for achieving strategic and operational goals against Japan. But the bomber was successful in ways that planners and aircraft designers had not anticipated. With LeMay's operational adaptations, the technology-based doctrine of precision daylight bombardment gave way to the necessity of military expediency. The technological developments that drove the AAF's initial employment of the B-29 proved to be least important in the successful conduct of strategic bombing against Japan. Touting the technological advances of pressurization and remotely controlled defensive armaments, the B-29 succeeded not as a high-altitude precision bomber but as a low-altitude area bomber using incendiaries against highly vulnerable Japanese cities. Range, payload, and adaptability became its greatest assets.

Taking into account the costs of both the unforeseen difficulties and the necessary adaptations, the B-29 was a costly high-maintenance tool for use in achieving wartime objectives. Given the probable cost of the alternatives, however, the B-29 was almost certainly well worth it. The bomber was awesome in sheer killing power alone; the strategic bombing survey determined that the B-29s caused 330,000 fatalities and 806,000 injuries, far exceeding Japan's 780,000 combat casualties for the entire war. And Japan's economy was twice destroyed, with B-29s participating in both arms of the economic strangulation of Japan—destroying industries from the air and laying mines to cut off imports by sea. With or without the technology of the atom bomb, the technology of the B-29 was a war winner. The experience in the Japanese theater offers valuable insight into the successful application of emerging technology in war.

Appendix

Timeline of Events

January 1940	Army Air Corps design requirement for VLR bomber
21 September 1942	First Boeing XB-29 flown in Seattle
4 April 1944	Twentieth Air Force activated in the Pacific
5 June 1944	First XX Bomber Command mission from China; first B-29 mission of the war
June – August 1944	Guam, Tinian, and Saipan in the Marianas secured for B-29 operations
15 June 1944	First B-29 mission against mainland Japan from China
12 October 1944	First B-29 arrives in Saipan
1 November 1944	First B-29 reconnaissance mission over Japan from Saipan
24 November 1944	First B-29 raid on Tokyo from the Marianas
20 January 1945	LeMay replaces Hansell as Commander, XXI Bomber Command
25 February 1945	Experimental low-level incendiary raids against Tokyo
4 March 1945	First B-29 emergency landing on Iwo Jima
9 – 10 March 1945	Full-scale incendiary attack against Tokyo
April – May 1945	B-29s operate in support of Okinawa invasion

July 1944	Headquarters, Twentieth Air Force, transferred from the United States to Guam
16 July 1945	Gen Carl Spaatz assumes command of the newly created US Army Strategic Air Force
6 August 1945	First atomic bomb dropped by a B-29 on Hiroshima
9 August 1945	Second atomic bomb dropped on Nagasaki
14 August 1945	A record 809 B-29s bomb targets in Japan; Japanese government surrenders

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